CLASSIFICATION AND MAPPING

OF THE PATUXENT ESTUARY SHORE ZONE

Vol. VI

By

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February 1974

The work presented in this report was undertaken as a part of the Wetlands/Edges Program of the Chesapeake Research Consortium, Inc. with funds provided by the Research Applied to National Needs Program of the National Science Foundation.

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PREFACE

The study reported herein was designed to provide basic geomorphic information about the shore zone of the Patuxent sub-estuary of the Chesapeake Bay. Such information has been needed for the orderly planning and development of this tributary. In addition to being designed to be useful to management planners, the study was also designed to provide a spatial environmental framework for ecological studies in which landform characteristics and geomorphic processes are important as system components. Finally, classification and mapping procedures developed for the Patuxent should be applicable to the entire shore zone of the Chesapeake Bay and its other estuaries as well as to the shore zone of estuaries in other parts of the world.

This investigation was undertaken as a component of the Wetlands/Edges Program of the Chesapeake Research Consortium, Inc. under Grant No. G.I. 34869 from the Research Applied to National Needs program of the National Science Foundation. Dr. Frank Ahnert served as principal investigator for the project.

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INTRODUCTION

Purpose of this investigation

Estuaries are transitional features between the open sea coast which is predominantly shaped by waves that move approximately normal to the shoreline, and rivers whose morphological activity is dominated by a uni-directional current that flows between more or less parallel banks. Currents in estuaries alternate in direction and vary in intensity with the rhythm of the tide; the shorelines of estuaries tend to flare seaward, and as the width of the estuary increases, wind fetch and wave attack gain in importance. While there is a great amount of literature on the geomorphology of rivers and of sea coasts, the geomorphology of estuaries has received much less attention, except with regard to their functions as waterways. Only in recent years have estuaries come to be recognized more broadly as important, even critical, components of the environment (Lauff, 1967). Many of the world's urban agglomerations lie on the banks of estuaries, use them for transport, recreation, and waste disposal, and thus affect them as well as are affected by them.

In the eastern United States, the Chesapeake Bay with its tributaries constitutes a system of estuaries of which some bear the full impact of urbanization (the Patapsco, upper Potomac, and lower James estuaries), others are being gradually enveloped by the expanding suburban sprawl (most of the other estuaries on the Western Shore of the Bay), while still others have retained their predominantly rural character. The Patuxent estuary, located between the Washington, D. C. urbanized area and the Bay shore, belongs in this last group. Owing to its proximity to Washington, D. C., the Patuxent has increasingly become the target of recreational and suburban development which requires careful planning if the scenic beauty and environmental function of the estuary are to be preserved.

Regional planning along estuaries is particularly concerned with the characteristics of the shore zone, that is, of the nearshore land and the nearshore water, and with the possible uses of this zone for settlements, parks, marinas, and industrial or commercial establishments.

The present study attempts to provide basic geomorphic information about the shore zone of the Patuxent estuary and thus seeks to assist in the latter's orderly planning and development. This is done through an inventory of existing geomorphic shore zone features, arranged according to a simple descriptive classification scheme, and through the mapping of the occurrence and distribution of these shore zone features along the estuary. Besides being of use for the planner, such an inventory also presents a spatial environmental framework for those ecological studies in which landform characteristics and geomorphic processes are important as system components. Last but not least, the inventory can serve as a base study for a comprehensive geomorphologic investigation of the estuary.

The classification and mapping procedure developed here for the Patuxent estuary can be applied to the entire shore zone of Chesapeake Bay and its other estuaries, as well as to estuaries elsewhere in the world. In this sense. the present project may be regarded as a pilot study.

BRIEF DESCRIPTION OF THE PATUXENT BASIN AND ESTUARY

The basin

Located between the Patapsco River to the northeast and the Potomac River to the southwest and south, the Patuxent River is a major tributary to Chesapeake Bay on the western shore of Maryland (Fig. 1). Because of the competition of the two neighboring rivers, the drainage basin of the Patuxent is unusually elongated; although the basin is over 150 km (90 miles) long, its width nowhere

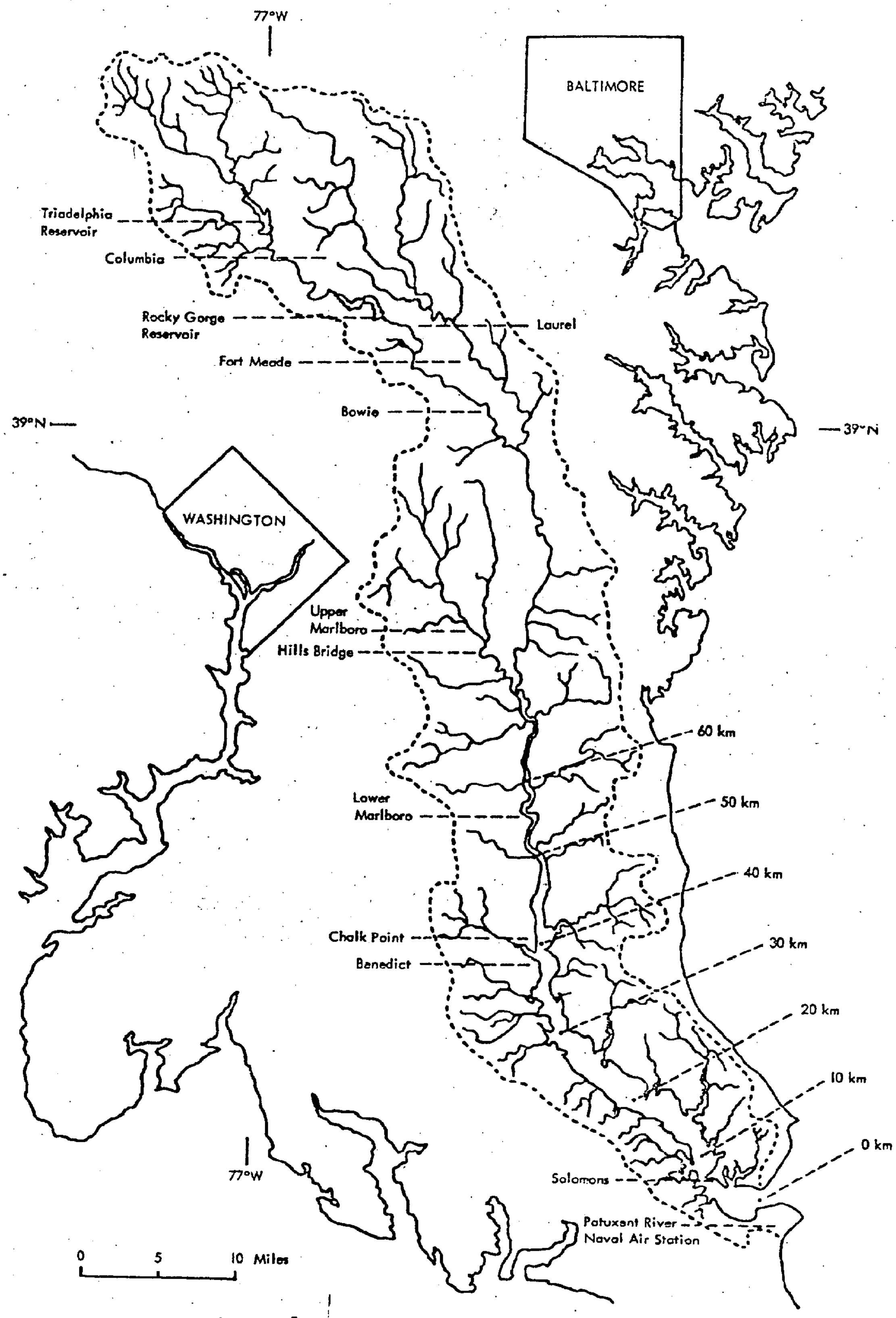

Figure 1: Orientation Map of

THE PATUXENT RIVER BASIN

exceeds 25 km (16 miles). Its area of about 2400 km^2 (932 square miles) constitutes nearly one tenth of the total land area of Maryland. The entire basin lies in the Piedmont and the Coastal Plain, between sea level and 240 m (800 ft.) elevation. Local relief, measured as the elevation difference between the river and the nearest point on the basin divide, is about 60 - 90 m (200 - 300 ft.) in the Piedmont and 30 - 75 m (100-250 ft.) in the Coastal Plain. With such low relief, steep slopes are rare in the Patuxent Basin, and under the pre-settlement natural forest vegetation soil erosion by overland flow probably was slight. Since the clearing of land, however, the easily erodible loam soils of the Piedmont and the fine-grained sedimentary materials of the Coastal Plain have contributed great amounts of sediment load to stream channels. There are no sediment gaging stations in the Patuxent basins. However, from the information available for other Maryland streams (U.S. Geol. Survey, 1969), an order-of-magnitude estimate would conservatively place the mean annual sediment yield at $40t/km^2/yr.$, or 96000t/yr. for the entire Patuxent basin. In a century, this adds up to 9.6 million tons, or (at a specific weight of 2.5) about 3.8 million m^3. Most of this sediment is probably deposited in the estuary.

The estuary

The lower half of the original Patuxent River channel has been drowned, and thus converted into an estuary, by the postglacial rise of sea level. From the mouth at Drum Point to the landward limit of tidewater at Hill's Bridge, the estuary is 77 km (48 miles) long. The lowermost 30 km, between Drum Point and Sheridan Point, are oriented N.W. - S. E., while the upper 47 km follow a N. - S. orientation (Fig. 1). For convenience, locations in and along the estuary are specified by their distance in km from the mouth. The width of the estuary narrows generally from the mouth to the head of tide, but in detail the estuary consists of a series of wide pool-like sections connected by narrows

(See the width diagram in Fig. 2). The three widest pools occur in the lower, S.E. - oriented sections of the estuary, namely at km 2.0 near Solomons, where the estuary is 3.6 km wide, at km 10.0 near Half Pone Pt., where it is 3.8 km wide, and at km 20.0 near Hollywood shores, where the greatest width of 4.0 km is reached. The intervening narrows lie at km 7.5 (Point Patience) and at km 18 (Broomes Island) and are 0.7 km and 1.5 km wide, respectively. Between km 30.0 (near Sheridan Pt.) to about km 45.0 (near Deep Landing) the pools are considerably shorter, and the width of the estuary fluctuates between 1.8 - 2.2 km for the pools and 0.9 - 1.3 km for the narrows. The sudden change in the wavelengths and amplitudes of the width curve (Fig. 2, depth and width along estuary) at km 30.0 indicates the difference of this section from that downstream. It is not certain whether this change is causally related to the change in direction of the estuary from S. to S.E. at Sheridan Point.

From km 45.0 to km 49.0 the estuary narrows progressively and rather dramatically to 0.3 km; this is the only truly funnel-shaped section of the Patuxent estuary. The narrowing is accompanied - and brought about - by the existence of broad tidal marshes on the right bank along this section. The combined width of marsh flats and estuary is approximately the same as that of the open estuary at km 45.0 namely, about 1 km, and indeed the same width of estuary and marshlands combined continues with minor fluctuations upstream to the head of tide (see Fig. 2). Above km 49.0, the estuary meanders within this marsh belt, and its outline displays the characteristic shapes of estuarine meanders: elongated, oval pools in the straight reaches that are separated by narrows at the bends. This morphological phenomenon is particularly well developed in the stretch from km 54.0 below White Landing to km 68.0 above Lyons Creek Wharf. The estuarine meanders of the Patuxent have previously been described by Ahnert (1960). Upstream of km 68.0, the estuary takes on the characteristics of a river channel with parallel banks - except for the large,

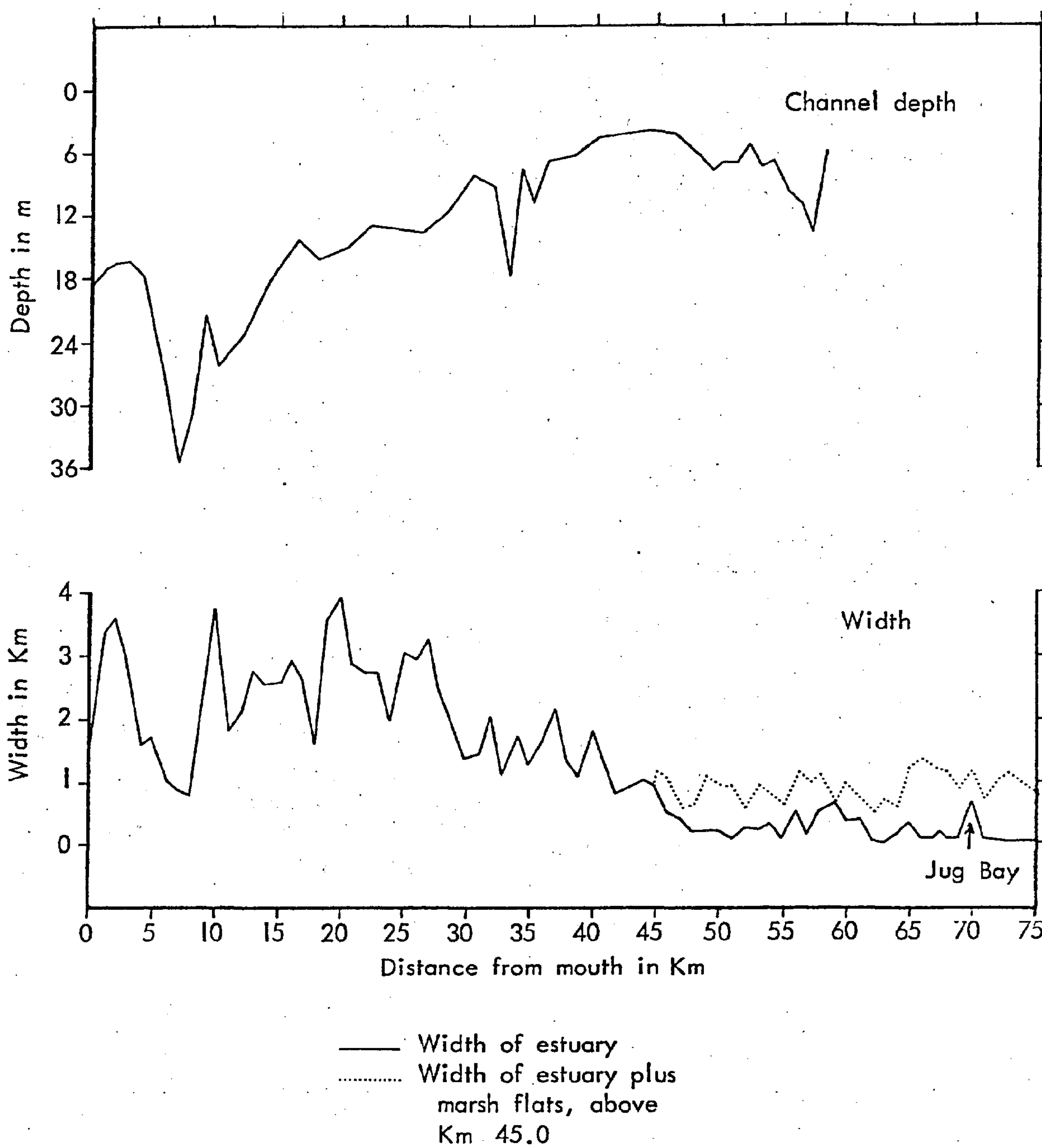

Figure 2: Depth of thalweg (top) and width (bottom) of the Patuxent estuary. Depth information is only available from the mouth (km 0.0) to km 58.0.

shallow pool of Jug Bay at km 70.0 which appears to have been formed by a shift of the channel and accompanying erosion of the marsh during an extreme runoff event in the first half of this century.

The depth of the thalweg or main channel of the estuary tends to increase overall in a downstream direction, from about 6 m near the mouth of Hall Creek at km 58.0 to 18 m near Drum Point at km 0.0 (Fig. 2). The resulting mean thalweg gradient of 0.0002, or 2 m per 10 km, could have been the gradient of the Patuxent River during the last glacial low position of sea level, when the Patuxent flowed into the Susquehanna in what is now Chesapeake Bay. Since that time, estuarine processes have locally modified the bottom configuration with erosional scouring in some places and depostion in others. Most pronounced is the deep scouring of the estuary channel down to 35 m at Point Patience (km 7.0), where the estuary narrows to 0.9 km between two pools that are more than four times as wide. Two other places of pronounced local scouring occur below Benedict at km 33.0 and km 35.0 and above White Landing at km 57.0. The two scour locations near Benedict coincide also with narrows, relatively speaking; but not all narrows in the estuary are associated with scour, nor are overdeepened stretches of the channel only found at narrows. Undoubtedly the availability and possible deposition of sediment plays as important a part in the morphological modification of the estuary bottom as does the variation in width. In terms of the continuity of cross-sectional area, even the greatest scour depth at Point Patience does not sufficiently compensate for the lesser width: the cross-sectional area there is only about half as large as in the pools above and below. This means that higher tidal current velocities are required in the narrow passage.

Upstream from the Benedict bridge (km 35.5) the channel tends to be much shallower than below (Fig. 2), with the exception of a few local scour depressions. The thalweg is undivided along the entire estuary; only below

Solomons and above Point Patience short secondary channels developed near the shore - in both cases along the left bank.

The mean tidal range in the Patuxent estuary increases landward from 0.4 m (1.3 ft.) at Drum Point (km 0.0) to 0.75 m (2.5 ft.) at Nottingham (km 61.6). The tidal currents have average maximum velocities of 0.4 knots (0.2 m/sec.) near Drum Point, rise to 0.8 knots (0.4 m/sec.) for the ebb current and 0.5 knots (0.3 m/sec.) for the flood current at Point Patience, and reach 1.1 knots (0.6 m/sec.) for the flood and 0.9 knots (0.5 m/sec.) at Lyons Creek Wharf (km 67.0).

Tide phase and current phase shift in their relative position as they travel up the estuary (Ahnert, 1960). At Drum Point the maximum flood current occurs between mean water of the rising tide and the following high water, about an hour to an hour and a half after mean water, and the maximum ebb current occurs at a corresponding time between mean water of the falling tide and the following low water; in other words, maximum flood current and maximum ebb current occur at different water levels. In the upper estuary near Nottingham, however, the maximum flood current occurs at mean water of the rising tide and the maximum ebb current at mean water of the falling tide, so that both currents occur at the same water level. Since in curving reaches of the estuary the ebb and flood currents tend to veer towards opposite banks, current-induced bank erosion can occur on both sides of the estuary at the same level. This circumstance is an important factor in the development of estuarine meanders with their oblong pools and narrow bends in the section of the estuary that lies between km 49.0 and km 68.0.

PROCEDURE OF CLASSIFICATION AND MAPPING OF SHORE ZONE FEATURES

Features to be classified

The term "shore zone" recognizes that the shore line proper shifts with changing water level and wave height, and furthermore, that land and water on either side of the shore line interact with one another as components of the system. Landward and seaward boundaries of the shore zone are not clear-cut natural lines, but could be defined arbitrarily if needed. The present study does not attempt such delimitation; rather, it seeks to identify characteristic components of the shore zone and to classify them. These are: fastland and wetland, shore height, presence and height of active cliffs, presence and width of beaches, a measure of the nearshore depth and the long-term advance or retreat of the shoreline. Each of these categories is defined and subdivided into appropriate classes. The locations of each category along the estuary have been identified by interpretation of topographic and hydrographic maps, aerial photographs, and field checks. Data was then plotted with appropriate symbols on a map of the Patuxent estuary shore zone (Appendix A). The location, spatial and frequency distribution, and spatial association of these shore zone characteristics is then further analyzed. The characteristics are defined in the legend to the shore zone map (Appendix A), and will be discussed briefly below in the same sequence in which they appear on that legend.

Wetlands

The shore zone map (Appendix A) marks the boundary between wetlands, or marshes, and the higher, dry fastland by a line of short dashes. In this manner, the map provides basic information about the location, extent, and shape of wetland areas. Shore height symbols (see explanation below) on the fastland side of the wetland/fastland boundary indicate elevation of the fastland margin.

Shore height

Height of land near the shore line is related to the steepness of slopes and of the gradients of first order streams, and thus gives an indication of relative intensity of erosional processes on the nearshore land, and of relative rate of sediment supply to the estuary from this nearshore land. Where the shore line is being eroded by estuarine processes, the shore height also serves as a rough measure of the amount of material that has to be removed by such erosion, and, relatively, of the energy requirement for such erosion; to wear back a shore that is 6 m (20 ft.) high requires less energy than to wear back a 12 m (40 ft.) high shore by the same amount. The land surface fringing the estuary consists of a set of estuarine terraces, i.e. comparatively flat areas at several elevations that are separated by relatively narrow sloping surfaces. The lowermost terrace level is that of the recent tidal marshes or wetlands, very close to sea level. Above this lie several Pleistocene terraces, at elevations near 3 m (10 ft.; e.g., the vicinity of Trent Hall opposite Sheridan Pt. near km 30.0); near 7-8 m (25 ft.; e.g., at Parker Wharf on the left bank near km 24.0); a level near 13-14 m (45 ft.) occurs only in a few places close to the shore, for example, near the mouth of the Patuxent within 0.5 km of Drum Point. Still higher levels are even rarer close to shore; an example is the 21 m (70 ft.) high shore at Drumcliff opposite Broome Island (km 18.0).

On the available large-scale (1:24000) topographic maps, elevation is represented by contours, generally with a contour interval of 20 ft. (exactly 6.1 m). Using the map information, and bearing in mind the terrace morphology along the estuary, the classes of shore heights to be mapped were defined according to the highest contour that occurs within 120 m (400 ft.) of the actual shore line. Thus there are four shore height classes. Each class is defined and identified by a symbol in the legend of the shore zone map (Appendix A). Where the estuary is fringed by low wetlands, the height of fastland that borders on the wetland is indicated on the shore zone map by the same basic symbols, but without a connecting line.

This measure of shore height should not be read directly as a measure of nearshore slope. Because of the presence of terraces, the most probable surface configuration represented by each shore height symbol is that of a relatively flat surface, possibly dissected by streams, near the lower elevation limit set by the class definition, and bordering with a narrow, fairly steep slope on the estuary. Where that slope is an active cliff, it is so identified by a special symbol.

In many places the Pleistocene terraces that border on the estuary are dissected by valleys which constitute reentrants in an otherwise higher shore. Their location has been marked on the shore zone map (Appendix A) by a separate symbol, without indication of the size of the reentrant, but with the distinction whether the reentrant is now occupied by a stream or not.

Active cliffs

An active cliff is a near-vertical slope whose base is inundated and eroded by the water of the estuary with sufficient frequency to keep the slope in an unstable condition, without plant cover and soil development. Active cliffs have been included among the shore zone features to be mapped because they indicate the presence of intensive shore erosion. Three cliff height classes are distinguished on the shore zone map (Appendix A): 1. active cliff less than 6 m (20 ft.) high; 2. active cliff 6 - 18 m (20 - 60 ft.) high; and 3. active cliff more than 18 m (60 ft.) high.

Determination of the presence and the height of active cliffs was made mainly from air photos under the stereoscope. Additional information was derived from topographic maps. Field checks have shown that some cliffs in the lowest (less than 6 m) class had not been recognized on the air photos. It is therefore probable that low cliffs do exist in some locations where the shore zone map (Appendix A) shows none.

Beaches

The presence of beaches indicates that sedimentary materials are being deposited on the shore or are being transported along the shore. In addition, beaches have recreational potential, and offer some protection of the land behind the beach from wave attack at moderately high water levels. All beaches along the Patuxent estuary consist of sand, although small pebbles may be present locally. Where beaches occur, they are classified and mapped according to three classes: 1. beaches less than 10 m (33 ft.) wide; 2. beaches that are 10 - 20 m (33 - 67 ft.) wide; 3. beaches that are over 20 m (67 ft.) wide. The beaches are identified on air photos.

Nearshore depth

Depth of nearshore waters influences the amount of energy available for wave erosion and sediment transport at the shore line. It also affects the suitability of the shore for recreational uses such as swimming or the construction of piers and marinas. The depth classification that is used on the shore zone map is really a classification of the nearshore underwater gradient rather than of depth, since it is based on the distance of the 1.8 m (6 ft.) isobath from the shoreline. Four classes are distinguished, with the 6 ft. isobath being: 1. more than 360 m (1200 ft.) from shore; 2. 180 - 360 m (600 - 1200 ft.) from shore; 3. 90 - 180 m (300 - 600 ft.) from shore; and 4. less than 90 m (300 ft.) from shore.

The six foot isobath has been chosen as critical depth because it represents the depth at which waves of 3.6 m (12 ft.) length begin to shoal; waves of this order of magnitude are very common in small estuaries such as that of the Patuxent. The six foot depth is also a convenient depth measure for navigability by small boats. A third factor was the convenient circumstance that the six foot depth is marked by a continuous isobath on both the hydrographic chart and topographic maps, while other depths near this value are only indicated by spot depths.

Shoreline advance and retreat

Active cliffs, beaches and wetlands indicate by their presence qualitatively that shore line changes are occurring now, or have occurred in the not too distant past. A quantitative assessment of shoreline changes, however, is provided by the study of shore erosion in tidewater Maryland by Singewald and Slaughter (1949), which compares the location of the shoreline in the middle of the 19th century with that on recent surveys, and thus determines distance of net advance or net retreat of the shoreline over this time interval, which for surveys of the Patuxent estuary varies from 82 to 94 years. Dr. Turbit H. Slaughter of the Maryland Geological Survey has kindly made the large-scale manuscript maps of that study available, so that information from these maps could be included on the shore zone map (Appendix A).

Accuracy of the shoreline changes determined by Singewald and Slaughter is, of course, dependent upon the accuracy of surveys on which they are based. Occasional systematic differences, for example, a lateral shift of both shores of several small tributary estuaries by approximately the same distance, suggest the possibility that there are some systematic errors of position, at least in the small tributaries, on the nineteenth-century maps. Shorelines of the major navigable estuaries such as the Patuxent, seem fairly accurately represented.

For the shore zone map, shoreline changes were subdivided into a total of seven classes, namely: 1. no significant change; 2. retreat in three classes, 5 - 25 m (17 - 84 ft.), 25 - 50 m (85 - 170 ft.), and over 50 m (170 ft.); and 3. advance in three classes, with the same class limits as for retreat. The amount of change refers to the time interval (roughly 90 years) of the study by Singewald and Slaughter.

FREQUENCY AND SPATIAL DISTRIBUTION OF INDIVIDUAL SHORE ZONE FEATURES

After completion of the shore zone map, the occurrence and magnitude of all shore zone characteristics mapped were sampled along the estuary. The sampling points were spaced 0.5 km apart (measured along the channel line of the estuary), and at each such point features of the right bank and of the left bank were recorded separately. Sampling was restricted to the lower 59 km, since no depth information was available above km 59.0; the total sample size is therefore 238. Figure 3 shows the distribution of sampled features in a synoptic diagram. Also plotted in Fig. 3 was the width of the estuary, as it may be a relevant factor in the explanation of some of the other features. In order to facilitate the analysis of co-occurrence and covariation of these features, three $n \times n$ association matrices were constructed from the sampled information - one matrix for the entire estuary, another for the lower part (km 0.0 - 35.5), and still another for the upper part (km 36.0 - 59.0). Each cell of the matrices indicates how often in the total sample a given class of one feature is associated with a given class of another feature. Since the information contained in the matrices can also be derived from Fig. 3, the matrices are not reproduced here.

Frequency and distribution of wetlands

Wetlands occur at 56 sample sites, or about 23.5 percent of the sampled part of the estuary. Their spatial distribution is very uneven. The few

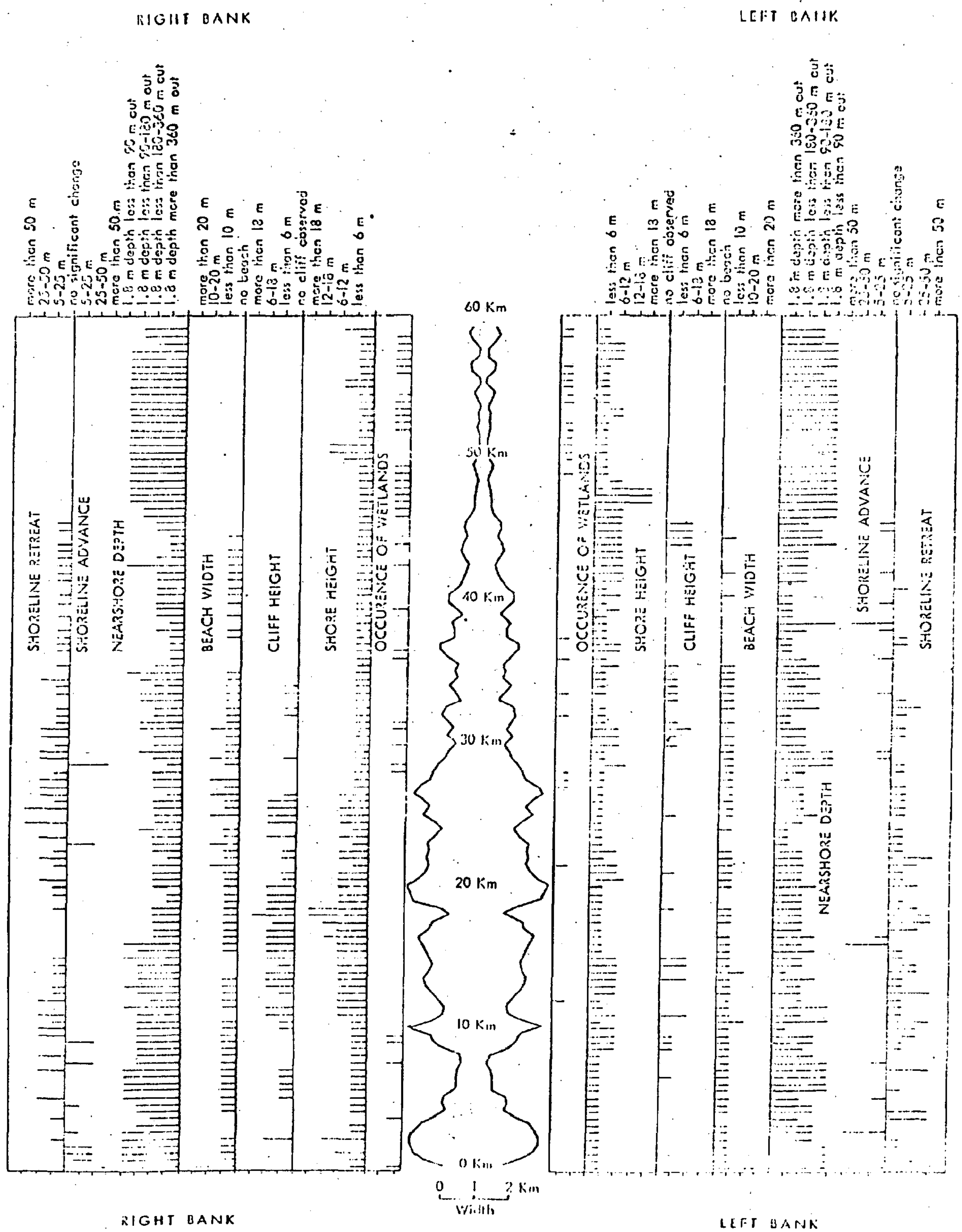

Figure 3: Synoptic diagram of the distribution of shore zone features along the Patuxent estuary. The width diagram along the center line is only intended to show the width, and not the actual outline of the estuary. The height of the linear marks indicates the size or intensity class of each feature present at a given location. Based on sampling along both banks of the estuary at 0.5 km intervals. For more detailed information see Appendix A (shore zone map).

wetland sites that occur in the lower estuary are mainly short stretches of fringe marsh (e.g., on the right bank at km 31.0), or are embayed marshes that have been formed by the filling in of former tributary estuaries (several examples occur on the left bank near Kitt Pt. km 27.0).

Above km 45.0, this pattern changes drastically. From here to the head of tide, wetlands predominate; apart from touching the fastland at the outside of estuarine meander bends, the estuary is virtually embedded in marshes, as the shore zone map shows (Appendix A). Marsh flats are the product of geologically recent filling of the innermost part of the estuary by sediment that was transported and deposited here from uplands of the Patuxent basin. Owing to the elongated shape of the basin (see Fig. 1), most of this sedimentary fill was brought to the estuary by the main river of the basin, the Patuxent, rather than by smaller streams that empty directly into the estuary.

Sediment transport and deposition in the estuary are subject to "backtracking" (Ahnert, 1960) under the influence of alternating tidal currents, and this phenomenon is the main cause for storage of the bulk of the sediment in the most headward portion of the estuary, instead of a wider distribution over the entire estuary. The sediment is fine-grained enough to be carried in suspension. As it enters the estuary from the upland, it is carried seaward by combined river and ebb current during falling tide. After low water slack, it is transported landward by the flood current during rising tide. At high water slack time, much of the suspended sediment is dropped; by the time the following ebb current has enough velocity to pick up these particles again, the water level has dropped already too far to reach all of them, especially since the current velocity needed to pick them up is much higher than the velocity at which they dropped out of suspension (Hjulström 1935). Where there is vegetation to hold particles and impede the currents (as on the marsh flats), sedimentation tends to be accelerated. In most of the estuaries in the Chesapeake Bay area, the wetlands dominate the landward reaches in the same manner. Along the edges of the estuary channel, fine-grained sediments of the wetlands are easily eroded, only to be redeposited elsewhere nearby. Bends of the estuary channel are thus modified in outline and transformed into the characteristic pools-and-narrows shape of estuarine meanders (Ahnert 1960, 1963). Once the estuarine meanders are established, they seem to reach an equilibrium between supply and removal of sediment that stabilizes both the outline and location of the meanders. The shore erosion study by Singewald and Slaughter (1949) revealed no significant change in the shoreline positions along the estuarine meander stretch of the Patuxent River (between km 49.0 and km 68.0) over a 90-year period, while there were many shoreline changes further seaward.

Most probably sedimentation in the landward part of the estuary was also influenced by the shape of the open estuary before sedimentation of the marsh flats began. This prior open estuary, whose width is equal to the distance between opposite fastland rims, was much narrower from km 42.0 to the head of tide than farther seaward, and the extensive marshes occur in this narrower part, from km 45.0 upstream (Fig. 2). From km 45.0 seaward to km 42.0, the sedimentary fill will be built up in the future in much the same way as it has been previously farther upstream; but below km 42.0 the estuary differs so much in width and outline that any sedimentary filling of this lower part will be very much slower.

This reasoning brings up the question of the rate of sedimentary filling that has occurred so far. According to Fairbridge (1961), the postglacial rise of sea level, which created the estuaries, was completed about 6,000 years ago (since then, there have been only minor fluctuations). Since that time, the fill zone in the Patuxent estuary has grown from about km 77.0 to km 45.0 at a mean rate of 5.3 km per 1,000 years. The absence of other than very local shoreline changes in this zone and at its lower end during the 90 years from mid-nineteenth to mid-twentieth century suggests that most of this sedimentation occurred earlier, and at a higher rate.

Distribution of shore height and active cliffs

Nearly two-thirds of the estuary shore (156 sample points) are occupied by the lowest shore height class, shores less than 6 m high. Even when the 56 wetland sites are subtracted, there remain still 100 (42% of the total) low fastland shores. The second shore height class, 6 - 12 m, with 72 sites, makes up nearly all of the remaining shore stretches; only 10 sites fall into the two higher classes. The spatial distribution of these shore heights is inherited from the spatial distribution of the Pleistocene Coastal Plain terraces and bears no relation whatsoever to the outline and function of the present estuary. A chi-square test verifies this null hypothesis.

Occurrence of cliff heights is related to shore heights only insofar as the cliffs cannot be higher than the shore. Of the 65 active cliff sites sampled, all are located below km 46.0 and all but four are located below km 35.5. This restriction of active cliffs to the lower estuary is not surprising; cliffs are formed by wave attack at the base of the shore slope and effective wave attack requires a minimum fetch across open water.

Another factor in the absence of cliffs above km 46.0 is that this section of the estuary is dominated by low wetland shores which protect the higher fastland slopes behind them.

Chi-square analysis indicates that there is no relationship between occurrence of active cliffs and nearshore depth. It seems that the effects of fetch outweigh those of nearshore depth. While very shallow depth impedes cliff erosion, great nearshore depth is frequently associated with small local width of the estuary and hence small fetch. Under these circumstances the chi-square result makes sense.

Harder to explain is the lack of correlation between the occurrence of active cliffs and occurrence of shoreline retreat.

Frequency and distribution of beaches

Beaches occur at 140 of the 238 sites sampled in the lower 58 km of the Patuxent estuary; all of these beach sites are located below km 45.0, which is also the point from which the large contiguous marsh areas extend upstream. Occasional patches of beach do occur above km 45.0 in places where the outside of an estuarine meander bend impinges upon the fastland margin, but are so small and so rare that the sampling missed them. Since there are 182 sampling sites below km 45.0, the 140 beach sites mean that 77 percent of the estuary shoreline in this lower section consists of beaches. Narrow beaches [less than 10 m (33 ft. wide)] were found at 130 sites. Wider beaches are confined to localities where the shape of the shoreline encourages convergence of longshore sand movement. Examples are the large cuspate sand accumulation at Drum Pt. (left bank at km 0.0), and beaches at the mouth of Helen Creek (left bank at km 10.5), and at Petersons Point (left bank at km 14.0).

The sand of the beaches is derived mainly from shore erosion rather than from the bottom of the estuary, and is being transported along the shoreline by waves and currents. In the section above km 45.0, beaches are largely absent because sandy sediments that make up the fastland are for the most part removed from erosional attack by the formation of tidal marsh flats, and because the fetch and hence the wave attack on the shoreline is greatly reduced.

Although the beach material is derived from erosion, shoreline where the beach is located may be retreating, neutral, or advancing. This is determined by whether, in the continuing process of longshore sand movement, the rate of removal is greater, equal to, or smaller than the rate of supply. It is, therefore, not surprising that a chi-square test revealed no significant relationship between the occurrence of beaches and shoreline retreat. More significant is the relationship between active cliffs and beaches; 90 percent of the active cliffs sampled have beaches at their base, as compared to only 78 percent of the sites without cliffs (between km 0.0 and km 35.5). The chi-square test of this relationship equals 12.2 and is significant at a less than 0.1 percent probability level. It may be concluded that active cliffs are the primary source locations of beach sand, and that the occurrence of beaches at locations without active cliffs is the result of longshore transport.

Distribution of nearshore depths

All four nearshore depth classes are represented in the sample survey: 28 sites with very shallow depth, 81 moderately shallow, 51 moderately deep, and 78 very deep, as defined in the legend of the shore zone map (Appendix A). Their occurrence is to some extent related to the width of the estuary for much the same reason that caused the relationship between depth of the channel and width of the estuary, namely, the continuity equation or rule of conservation of discharge that governs water movement in channels. Figure 4 shows the frequency distribution of channel widths for the four different nearshore depth classes. Occurrence of very shallow and of shallow depths seems to be little influenced by width, except that none of these depth classes occur where the estuary is very narrow. Their distributions appear fairly normal. With the moderately deep class, however, the frequency distribution becomes skewed, and even more so with the very deep nearshore depths. The maximum shifts to the low end of the width scale. Thus the narrower the estuary, the more probable is the occurrence of deep water close to shore.

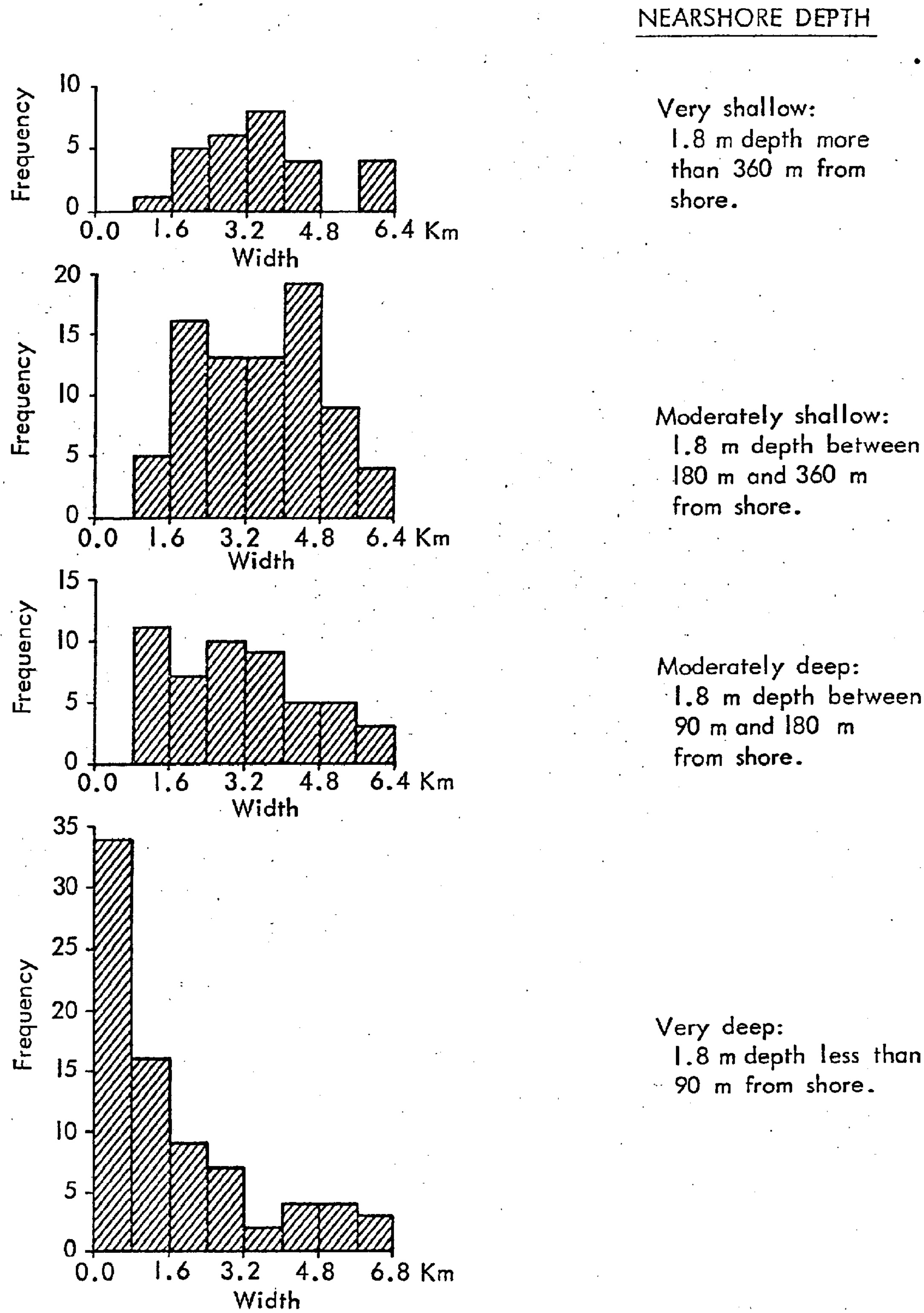

Figure 4: Relationships of nearshore depths to width of the estuary.

The synoptic diagram (Fig. 3) gives a summary of the spatial distribution of nearshore depth classes, and of their relationship to other features. Most striking is the fact that 44 out of the 78 sample sites in the very deep class lie above km 45.0, i.e. in the section of extensive tidal marshes where the channel is narrow. In the lower part of the estuary, a similar concentration of great nearshore depth occurs only in the narrow stretch around Point Patience (km 5.0 - 7.5), where also the greatest channel depths in the entire estuary are found. Elsewhere in the lower 45 km of the estuary, distribution of nearshore depths is varied and influenced by local conditions. The mouths of St. Leonard Creek (left bank, km 13.5) and Battle Creek (left bank, km 25.0), both major tributary estuaries, are deeper than the nearshore areas on either side of them, because both are deep open estuaries in which most sedimentation takes place near their head. Trent Hall Creek (right bank, km 32.0), Swanson Creek (right bank, 38.5), and Hunting Creek (left bank, km 40.5) are very shallow estuaries, shallower than the nearshore waters adjacent to their mouths. Where the deep channel of the estuary runs closer to one shore than the other, as just south of aptly named Deep Landing (at km 44.0 - 45.0) on the left bank, and near Eagle Harbour (at km 42.5) on the right bank, great nearshore depth on one side is accompanied by shallow nearshore water on the opposite side of the estuary.

Degree and distribution of shoreline change

Of the 238 sample sites, 108 were found to have retreated, 104 to have remained in the same position, and 26 to have advanced, during the approximately 90 years covered by the study of Singewald and Slaughter. Most of the shoreline change is confined to the lower part of the estuary, where greater fetch causes more erosion, transport, and deposition of material along the shore. The general trend is one of shoreline retreat. It is not possible to determine how much of the retreat is a consequence of minor transgression due to a slow rise in sea level, and how much is due to active shore erosion. Both factors may play a part, and thus account for the predominance of retreat. The rare occurrences of shorelines that have advanced may be explained as the result of very localized accumulation of sediments; however, only sometimes are they associated with wider beaches.

There does not seem to be a recognizable regularity in the association of shoreline changes with other shore zone features that were mapped. It may be that part of the reason lies in inaccuracies of the survey maps that were used for the determination of these changes.

THE SPATIAL ORGANIZATION OF THE PATUXENT ESTUARY

The preceding discussion sought to analyze the frequency and spatial distribution of individual shore zone features. This analysis is to be followed by a synthesis which seeks to identify composite types of shore zone environments, i.e., characteristic assemblages of these shore zone features, and to understand through the distribution of these types the spatial pattern of the estuary shore zone and rules that may be found to govern this pattern.

Major shore types

If one disregards shoreline changes, and eliminates feature associations that would be mutually exclusive (as, for example, a low shore with a high active cliff), then the shore zone features and their classes as distinguished in this investigation may be theoretically associated in a total of 208 possible combinations. Fifty-two of these combinations actually occur along the Patuxent estuary. Of the fifty-two, thirty-one occur only three times or less, for a combined total of fifty-seven sites in the sample of 238 sites. On the other hand, the eleven most frequent combinations account for 134 sites, or more than half of the entire sample, and may be considered especially characteristic for the Patuxent estuary. Most of the combinations may be arranged in four groups or major shore types: 1. wetland shore; 2. cliffless, beachless fastland shore; 3. cliffless, fastland shore with beach; 4. cliffed shore. Their characteristics and distributions are discussed below.

Wetland shore

This type has two subtypes, the wetland deepwater shore, and the wetland shallow-water shore. The deepwater subtype is by far the more important; it consists of extensive tidal marshes, without beaches or cliffs, associated with very deep or moderately deep nearshore water [1.8 m isobath less than 200 m (600 ft.) from shore]. All 36 sampled occurrences of this subtype lie between km 46.0 and 57.5, i.e. in the uppermost section of the sampled part of the estuary. The wetland deepwater shore is the dominant shore type in this section of sedimentary infilling of the estuary, and is approximately conterminous with the occurrences of estuarine meanders.

Shallow-water wetland shores (19 sampled sites) occur in isolated locations in the estuary below km 46.0. Some of these wetlands represent filled-in former small tributary estuaries, while others are local fringing wetlands. Since these small wetland shores lie adjacent to fastland shores, many have narrow beaches due to longshore transport of sand from the fastland.

Cliffless, beachless fastland shore

This type is represented by 47 sites in the 238-site sample; most of these are located above km 35.0. The absence of beaches, cliffs, or wetlands on these shores indicates that morphological processes are not very active.

It is possible to distinguish two locational and functional subtypes. One occurs mainly at scattered localities in the estuary below km 44.0, and most extensively on the left bank just south of Hunting Creek (near km 40.0); it has for the most part shallow and very shallow nearshore waters, which together with the relatively small width of the estuary in this reach tend to inhibit the development of cliffs and beaches. The other subtype occurs above km 46.0 and is confined to the outside bank of estuarine meander bends, where the estuary impinges upon the fastland area. Wave erosion is virtually absent here because of the small width; on the other hand, deposition of sediment is prevented by the fact that at these bends both the ebb and the flood currents run close to the shore, and the nearshore depth is invariably great. Representative sites of this type are located at Magruder Landing (right bank, km 51.5), Lower Marlboro (left bank, km 53.0), and White Landing (right bank, km 55.5).

Cliffless, fastland shore with beach

With 71 out of 238 sampled sites, this is the most frequent shore type in the estuary. Since the determination of presence or absence of cliffs was made on air photos, it may be possible that some of these sites actually have low cliffs that were not detected. The fastland adjacent to the shore is usually a flat, most often agriculturally-used terrace. The beach is most commonly very narrow, less than 10 m (33 ft.) wide. Shores of this type occur only in the open estuary below km 45.0. Some examples are located in several places between Drum Point and Solomons (left bank, km 0.0 - 3.0), as well as on the opposite right bank. Farther upstream, this type occupies shore stretches near Trent Hall (right bank near km 30.0), Benedict (right bank at km 35.0) and between Chalk Point and Eagle Harbour (right bank between km 39.0 and 42.5).

Cliffed shores

Sixty-five of the 238 sample sites have active cliffs; nearly all of the cliffed shore sites also possess a (usually narrow) beach. Cliffed shores occur mainly in the lower 35 km, where greater width and fetch favor wave attack on the shore. Type locations include the shore near Town Point (right bank at km 5.5) and the shore N. of Point Patience (left bank at about km 9.0) as examples of low cliffed shore, and Drumcliff (right bank at km 18.0) and Sandgates (right bank at km 23.5) for higher cliffed shores.

The geographical subdivisions of the Patuxent estuary

Analysis of the distribution of shore zone features and of shore zone types suggests regular patterns in these distributions that relate the character and geomorphic functions of shore zone types to their location along the estuary and thus to their environment.

Change of shore zone features and types from the mouth to the head of tide is not gradual. Rather, long estuary stretches in which there is little progressive change of the shore zone are separated by short stretches in which there is considerable change. Spatial change of the shore zone characteristics parallels, and is functionally related to spatial changes in the physical dimensions and dynamic properties of the estuary itself. The spatial distribution pattern of the four major shore zone types is summarized in Fig. 5.

Four major geomorphic subdivisions of the estuary can be distinguished; they coincide with the four subdivisions that were recognized earlier on the basis of the estuary's width and hydrologic regime.

Section I extends from the mouth to Sheridan Pt. (km 30.0). It is characterized by its N.W. - S.E. orientation, and by the great width and length of its pool-like basins, which provide a large fetch for almost any wind

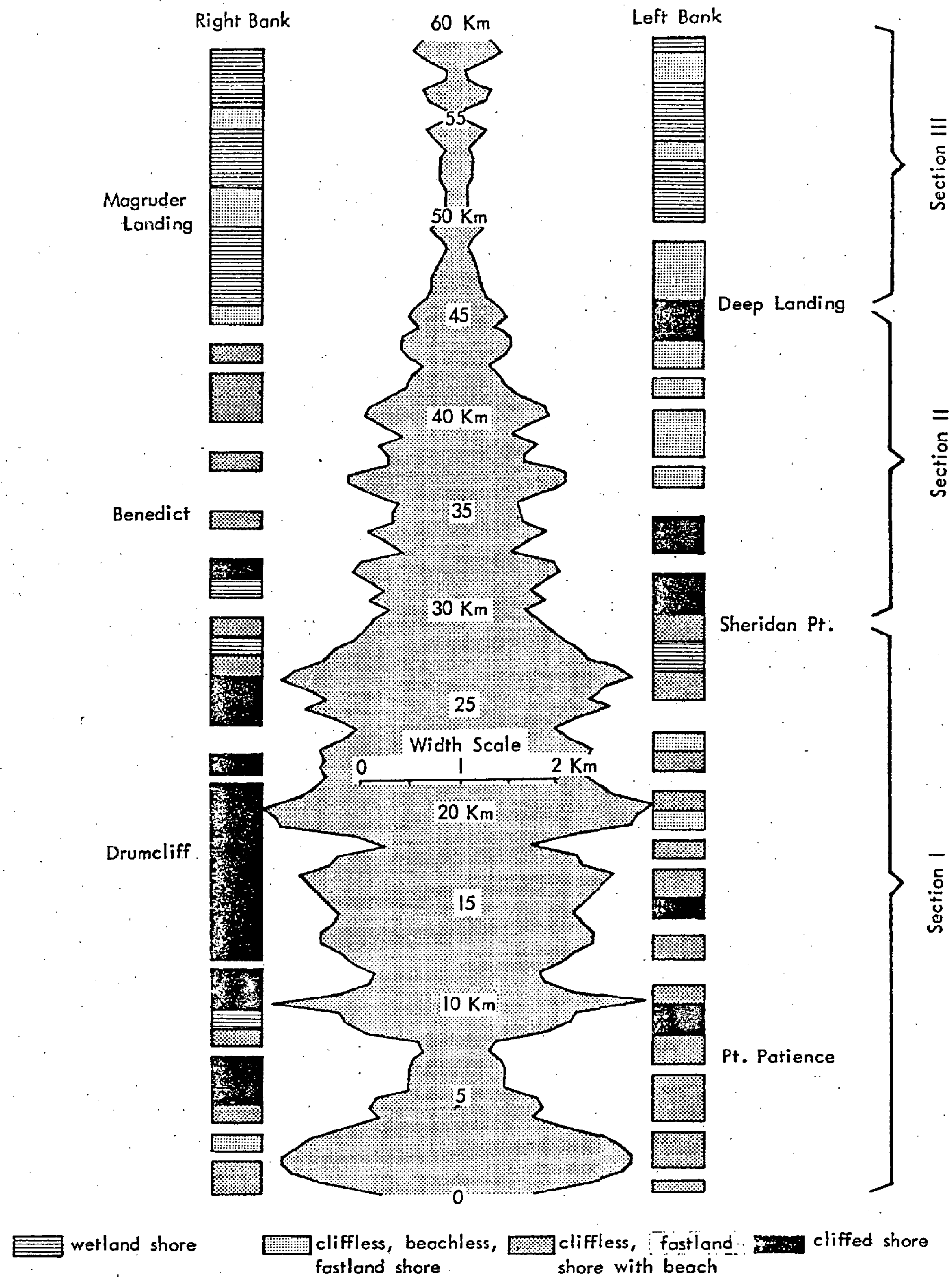

Figure 5: Generalized distribution of major shore types along the Patuxent estuary.

direction. The shore zone reflects this presence of relatively high wave energy by the high proportion of the cliffed shore type in this section. Beaches accompany the shores over most of their length, and wetlands occur very rarely - usually in the form of small pockets of sedimentary fills at the places where small tributary streams discharge into the estuary.

Section II, from Sheridan Pt. (km 30.0) to the vicinity of Deep Landing (near km 45.0) extends N-S., and still consists of wider and narrower parts, but is not as clearly organized into pools as Section I. Besides, the width of the estuary is considerably less. As a consequence, the frequency of cliffed shores is very much lower in this section. On the other hand, there are considerable stretches of low, cliffless and beachless fastland shores, i.e. of the morpholocically least active major shore zone type. Wetlands are as rare and small here as they are in Section I.

Section III, from Deep Landing (km 45.0) to Lyons Creek Wharf (km 68.0), begins with a four-kilometer funnel-shaped stretch due to the landward progressively increasing width of extensive marshes; the remainder of this section is marked by oblong pools and connecting narrower channels of the estuarine meanders. Along most of the length of this section, the wetland deepwater shore is dominant. Only at the outside of bends is it replaced by fastland shores, usually of the low, beachless type.

Section IV, finally, is estuarine only insofar as it still lies within the reach of the tide. It extends from Lyons Creek Wharf (68.0 km) to the head of tidewater at Hills Bridge (km 77.0). Wetlands occupy both banks most of the way, the channel is narrow, with little capacity to contain more than the river discharge from the Patuxent basin above the tide. The only anomaly here is the pool of Jug Bay (km 70.0). For all practical purposes, Section IV has been converted into a predominantly fluvial rather than estuarine reach.

These four sections group themselves quite obviously into two major units - the open estuary below km 45.0, with predominantly fastland shore, and the filled-in estuary, above km 45.0, with predominantly wetland shores. As was pointed out earlier, the location of the seaward boundary of wetlands near km 45.0 does not seem accidental, but rather a consequence of the narrower outer width - measured between opposing fastland margins - of the estuary above km 45.0. A phenomenon that requires further geomorphological study is the marked asymmetry in the occurrence of shore types in the lower two sections of the estuary, as shown by Fig. 5. Most cliffed shores in Section I lie on the right bank; in the upper part of Section II, there is a prevalence of beachless shores on the left bank. Any difference in exposure to prevailing winds alone would seem insufficient to explain the asymmetry.

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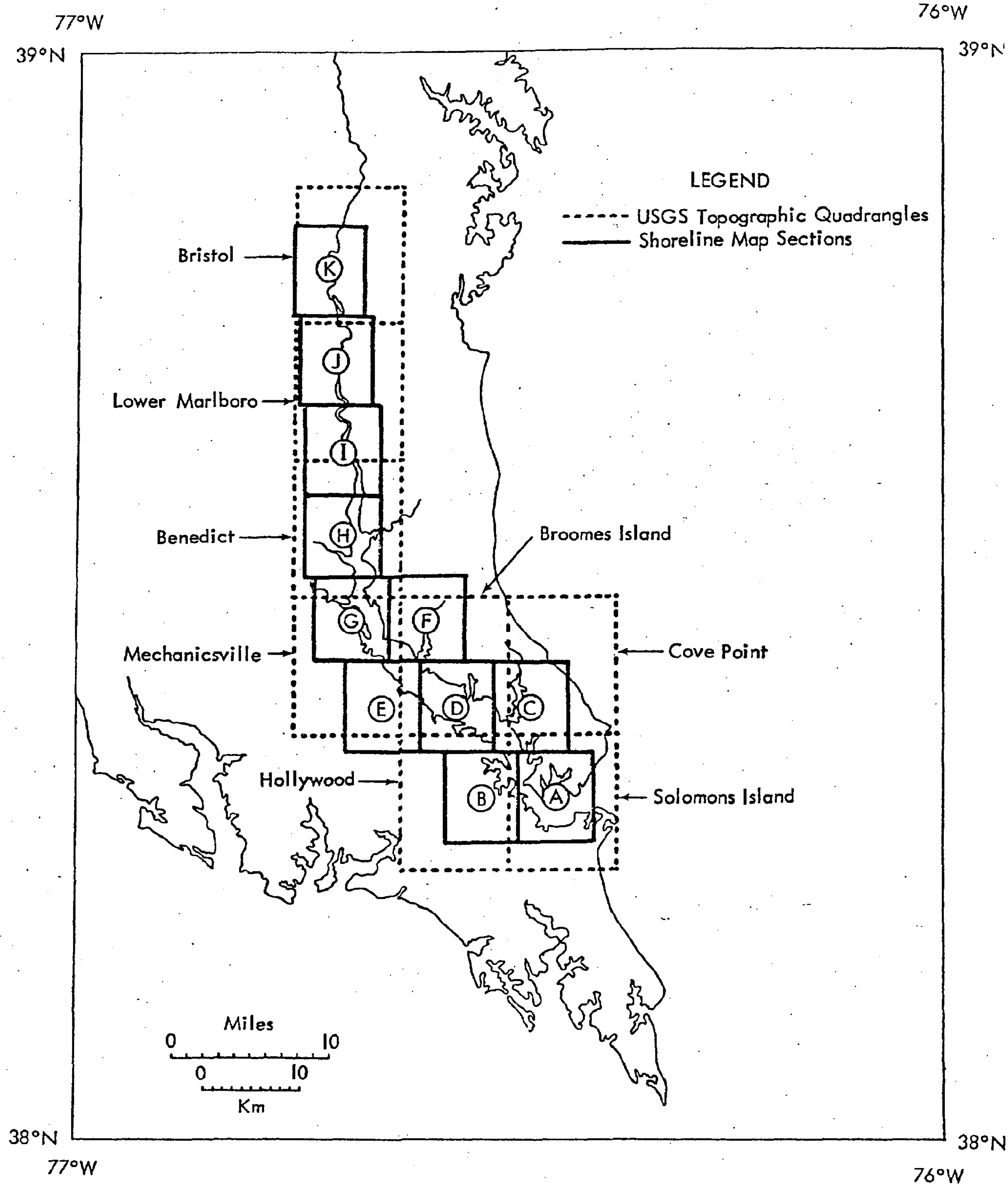
Appendix A: Map of the geomorphic shore zone features of the Patuxent estuary.

LOCATION INDEX
TO MAP SECTIONS A Thru K



LEGEND

WETLANDS

Landward Boundary of Wetlands

SHORE HEIGHT CHARACTERISTICS

(Behind Wetland)

Low Shore: 20 ft Contour > 400 ft from Shore

Moderately Low Shore: 20 ft Contour < 400 ft from Shore

Moderately High Shore: 40 ft Contour < 400 ft from Shore

High Shore: 60 ft Contour < 400 ft from Shore

Reentrant with Stream

Reentrant without Stream

ACTIVE CLIFFS

Active Cliff < 20 ft High

Active Cliff 20 – 60 ft High

Active Cliff > 60 ft High

BEACHES

Beach < 33 1/2 ft (10 m) Wide

Beach 33 1/2 – 67 ft (10 – 20 m) Wide

Beach > 67 ft (20 m) Wide

NEARSHORE DEPTHS

6 ft Isobath located > 1200 ft Offshore

6 ft Isobath located between 600 – 1200 ft Offshore

6 ft Isobath located between 300 – 600 ft Offshore

6 ft Isobath located < 300 ft Offshore

SHORELINE ADVANCE AND RETREAT (90 Year Shift)

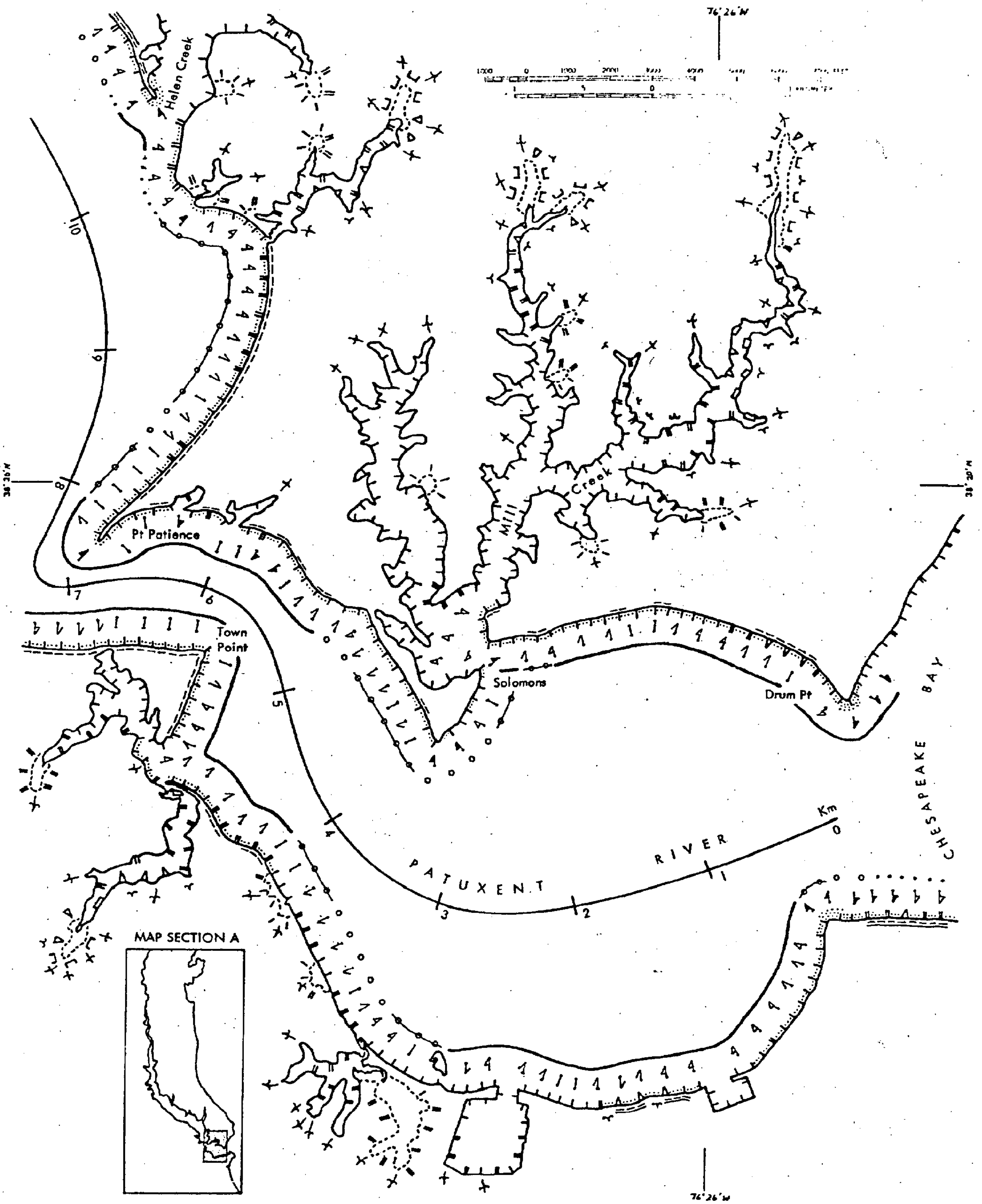
Direction of Change: Symbol Points Landward for Erosion and Offshore for Accretion

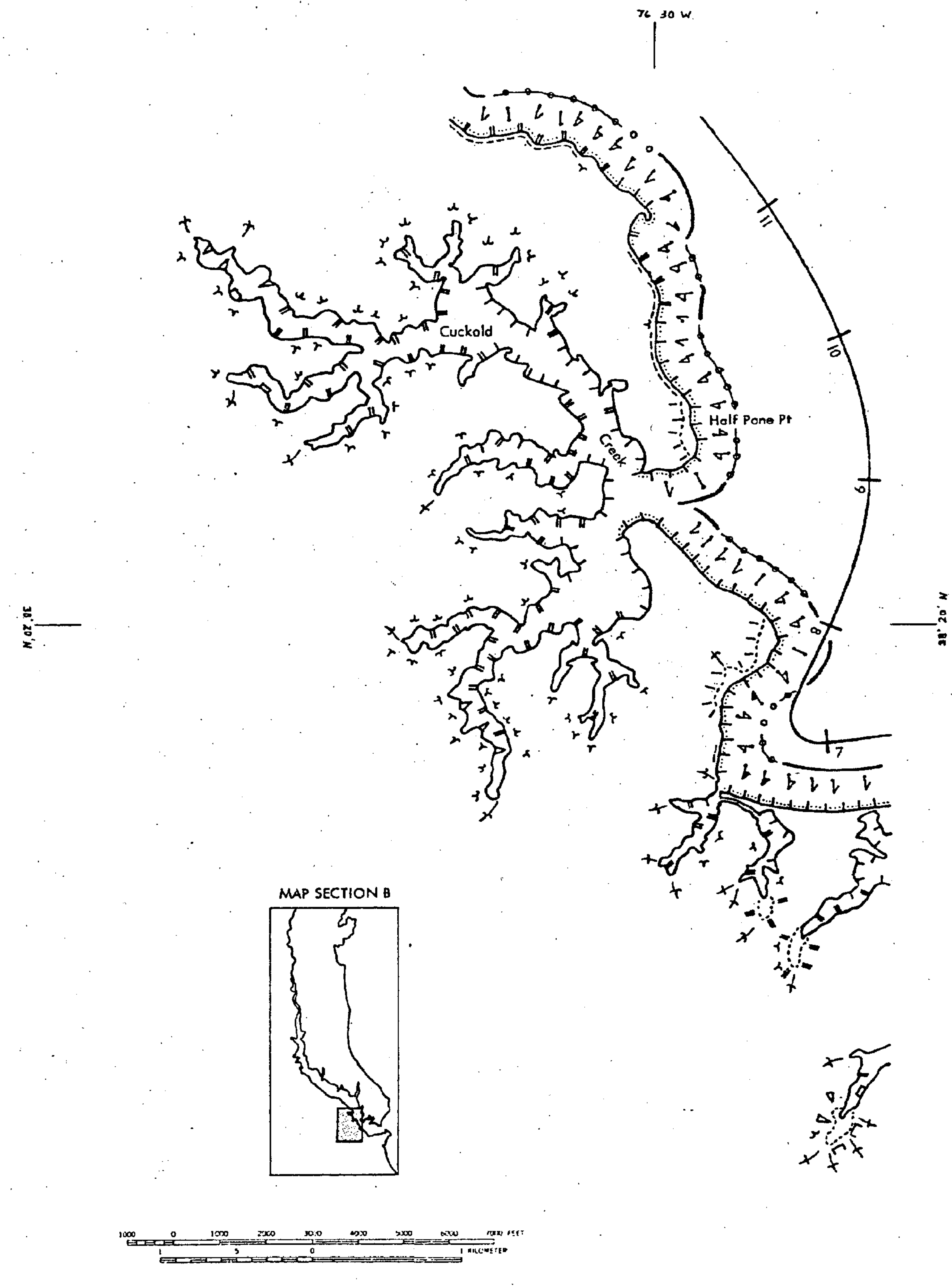
No Significant Change Detected

5 – 25 meters Change

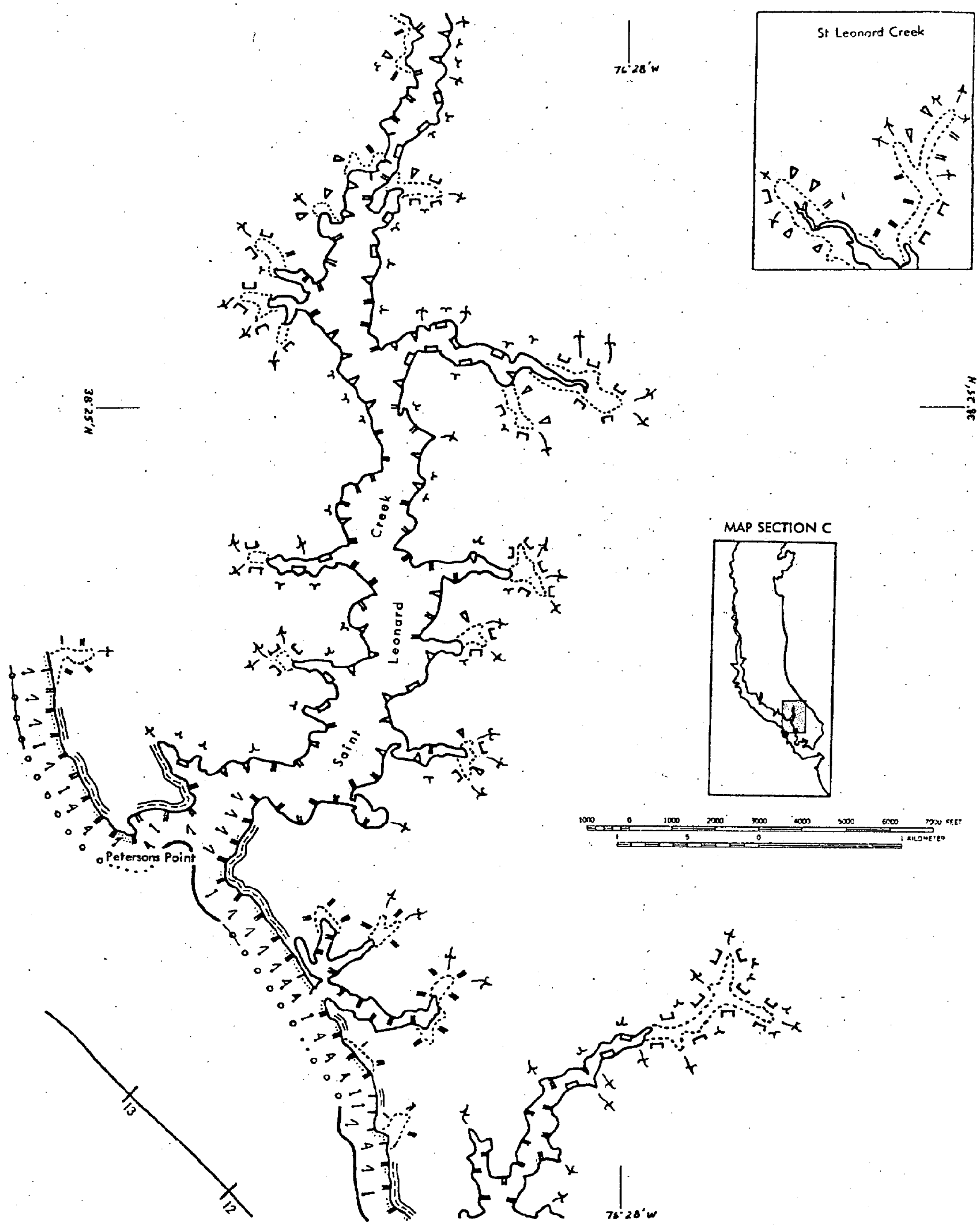
25 – 50 meters Change

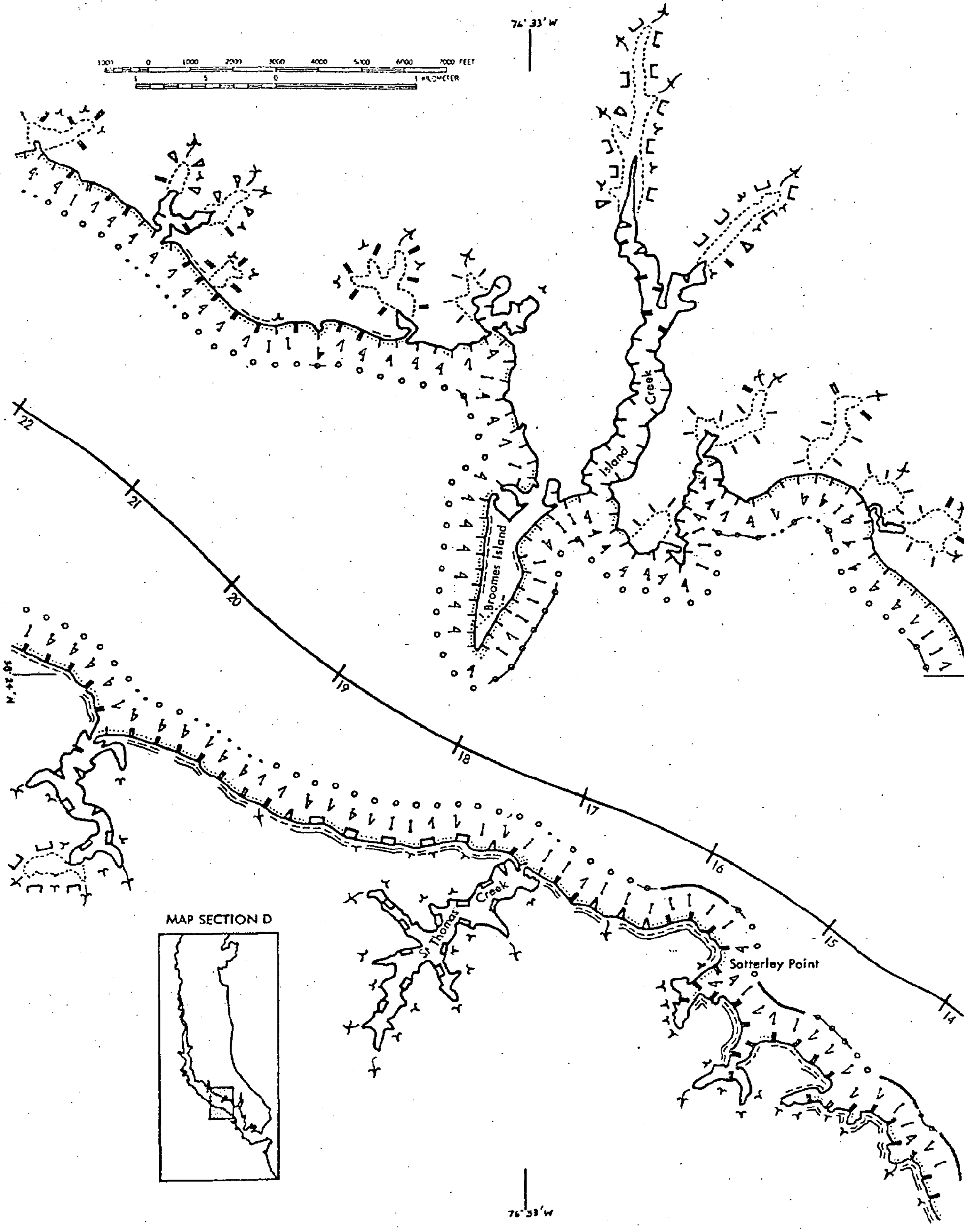
> 50 meters Change


76°26'W
Helen Creek
Pt Patience
Mill Creek
Town Point
Solomons
Drum Pt
PATUXENT RIVER
Km
CHESAPEAKE BAY
38°20'N
MAP SECTION A
10
9
8
7
6
5
4
3
2
1
0

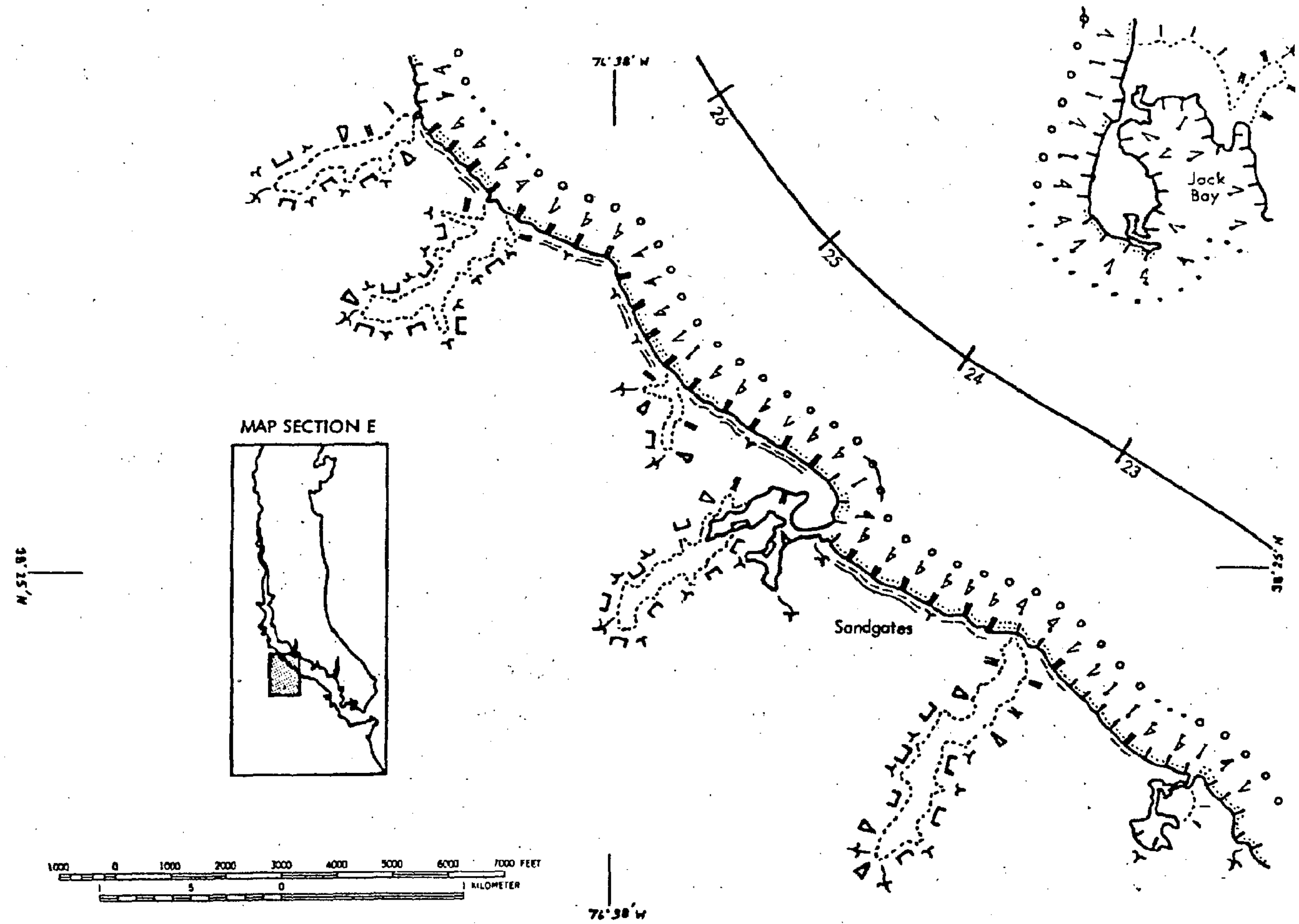


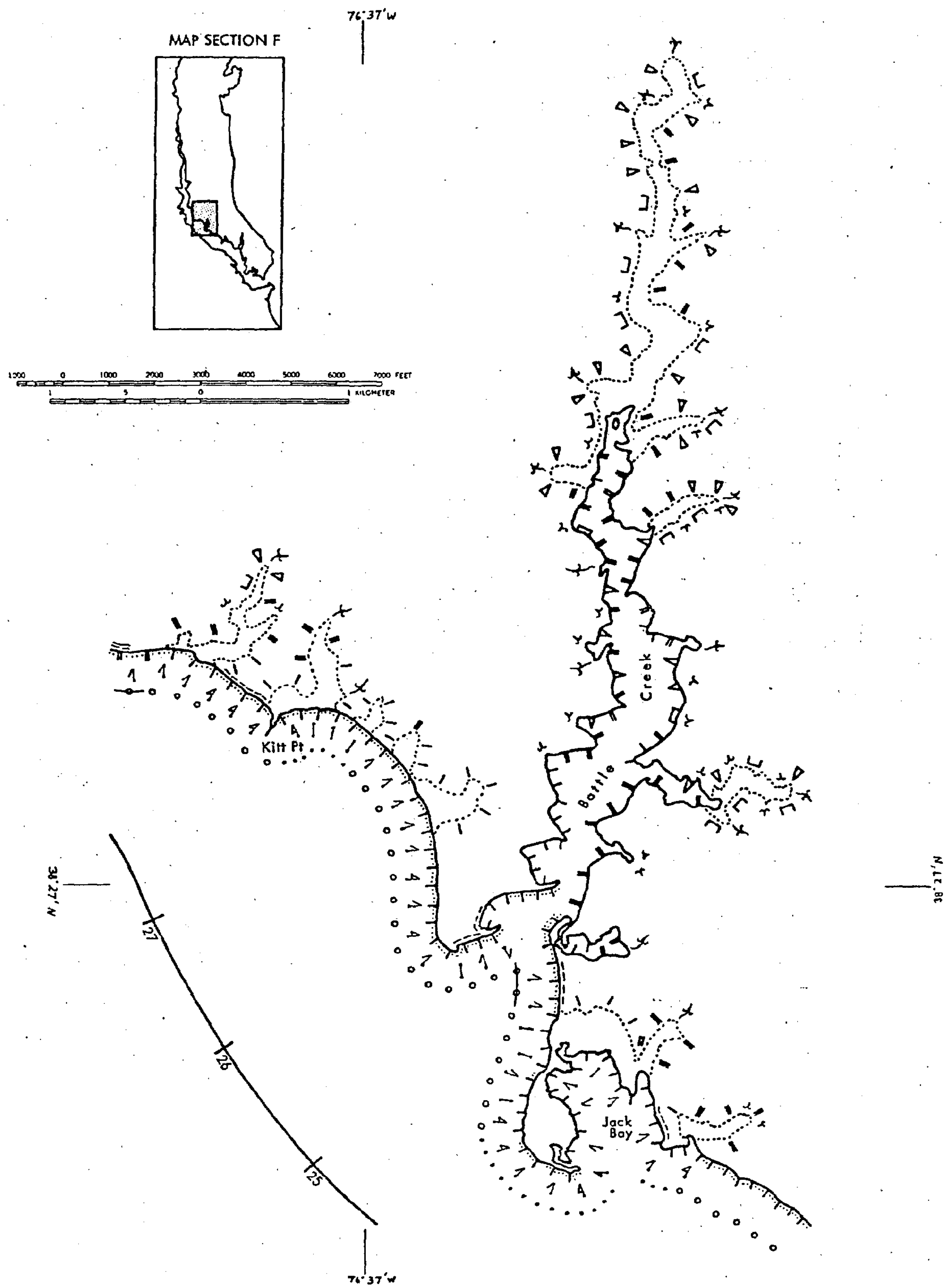
76 30 W
Cuckold
Creek
Half Pone Pt
11
10
9
8
7
38 20 N
MAP SECTION B

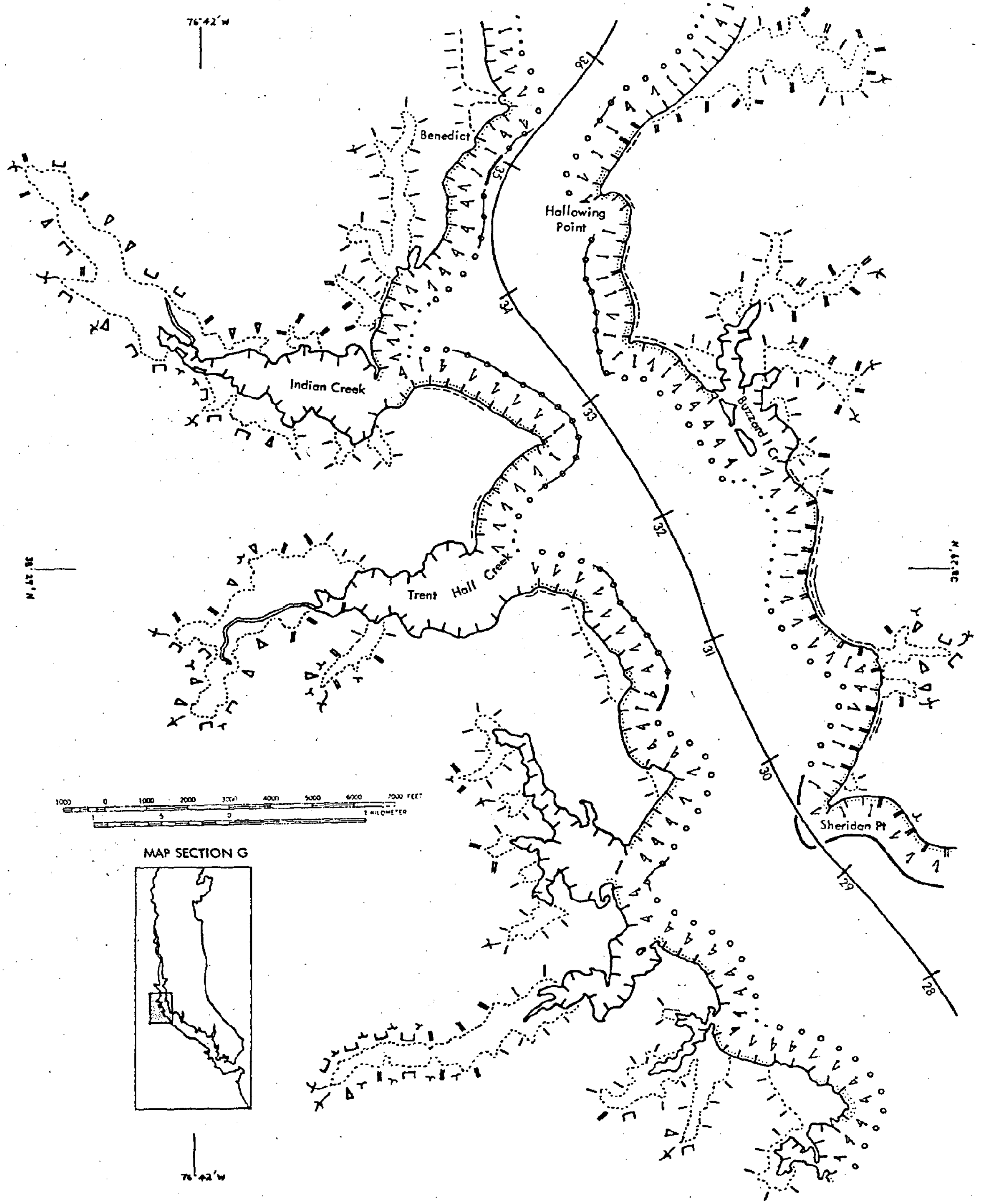

St Leonard Creek
76°28'W
38°25'N
Creek
Leonard
Saint
MAP SECTION C
Petersons Point
13
12
1 KILOMETER
7000 FEET

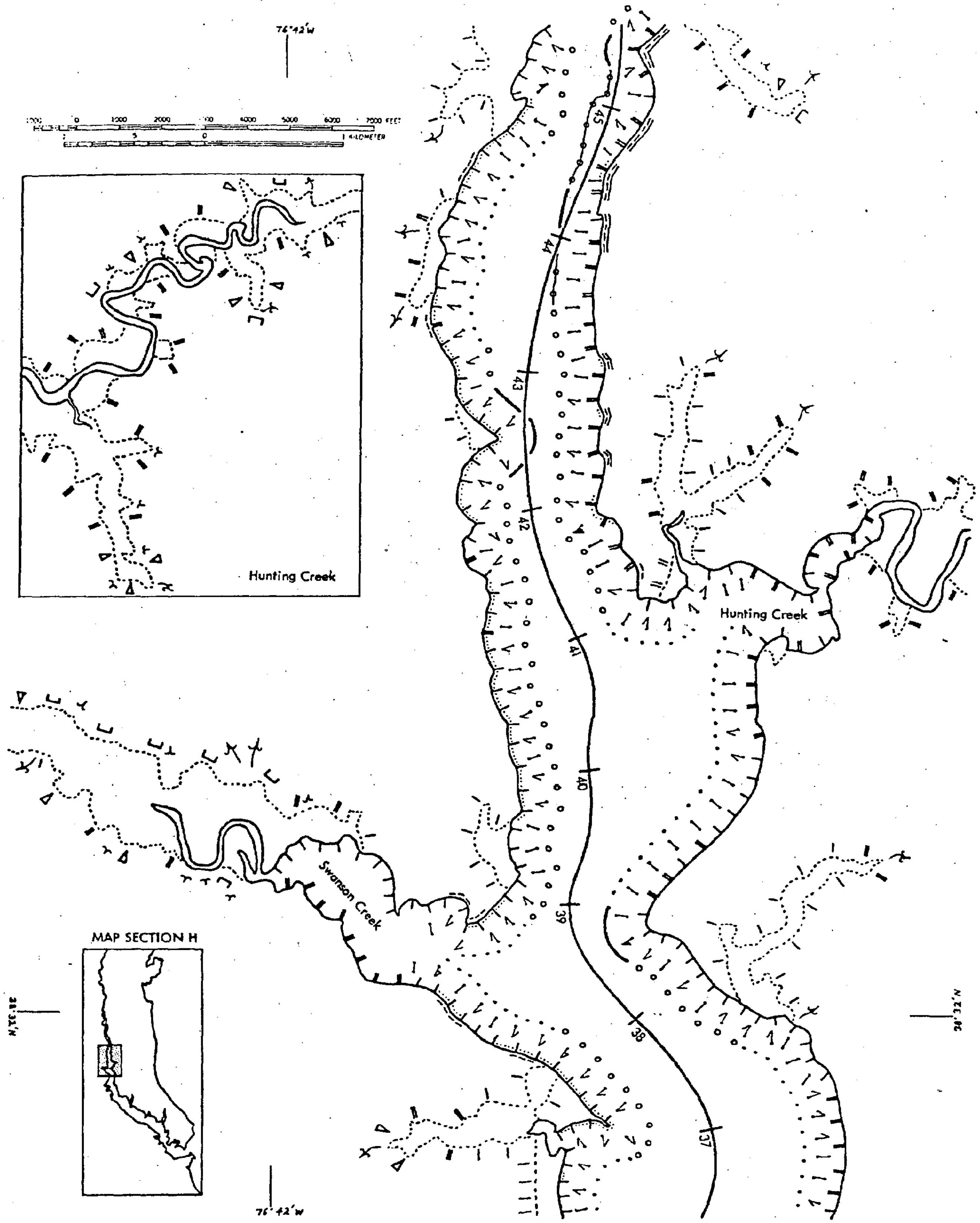


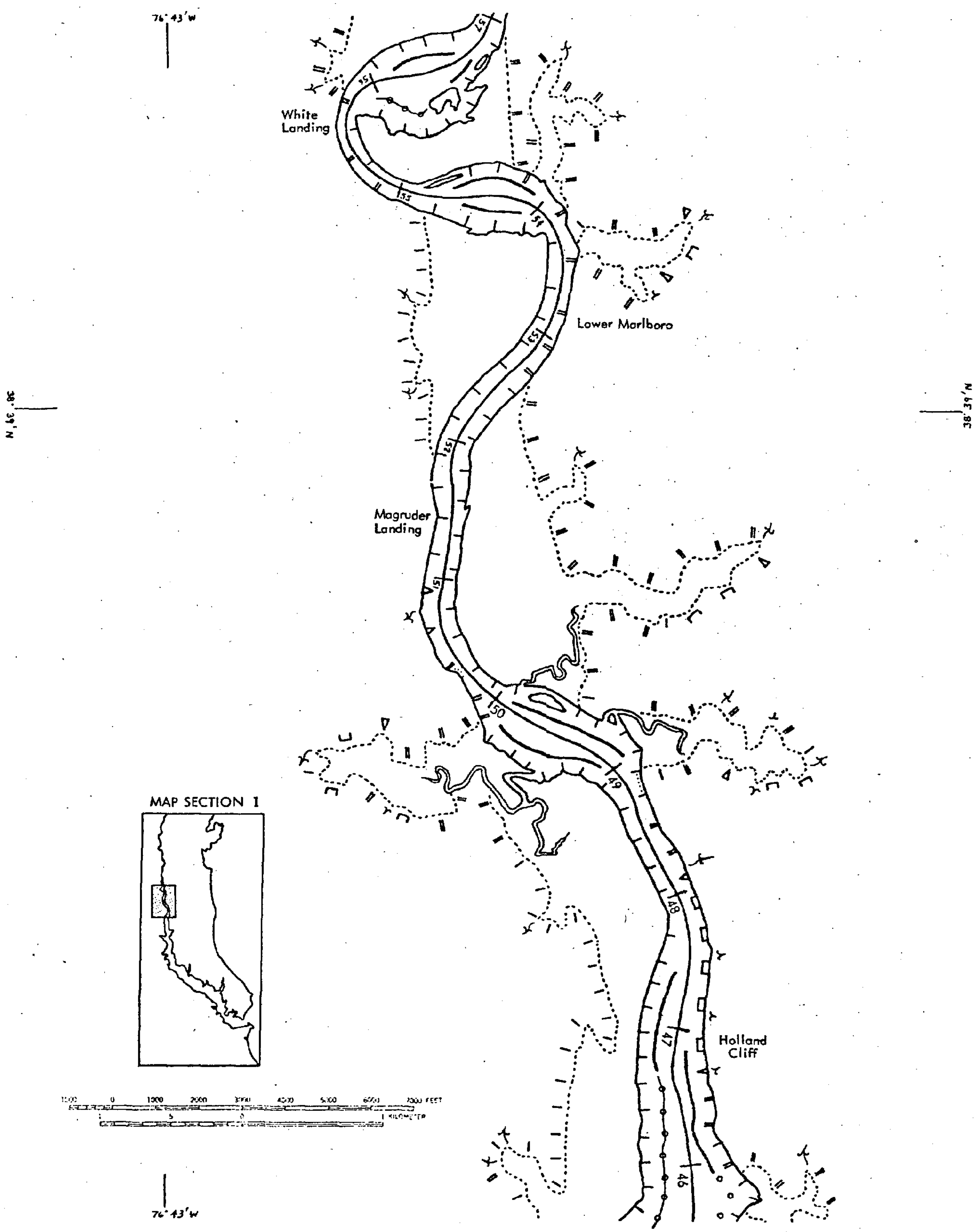
76° 33' W
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
Island Creek
Broomes Island
St Thomas Creek
Sotterley Point
MAP SECTION D
38° 24' N
76° 33' W
22
21
20
19
18
17
16
15
14

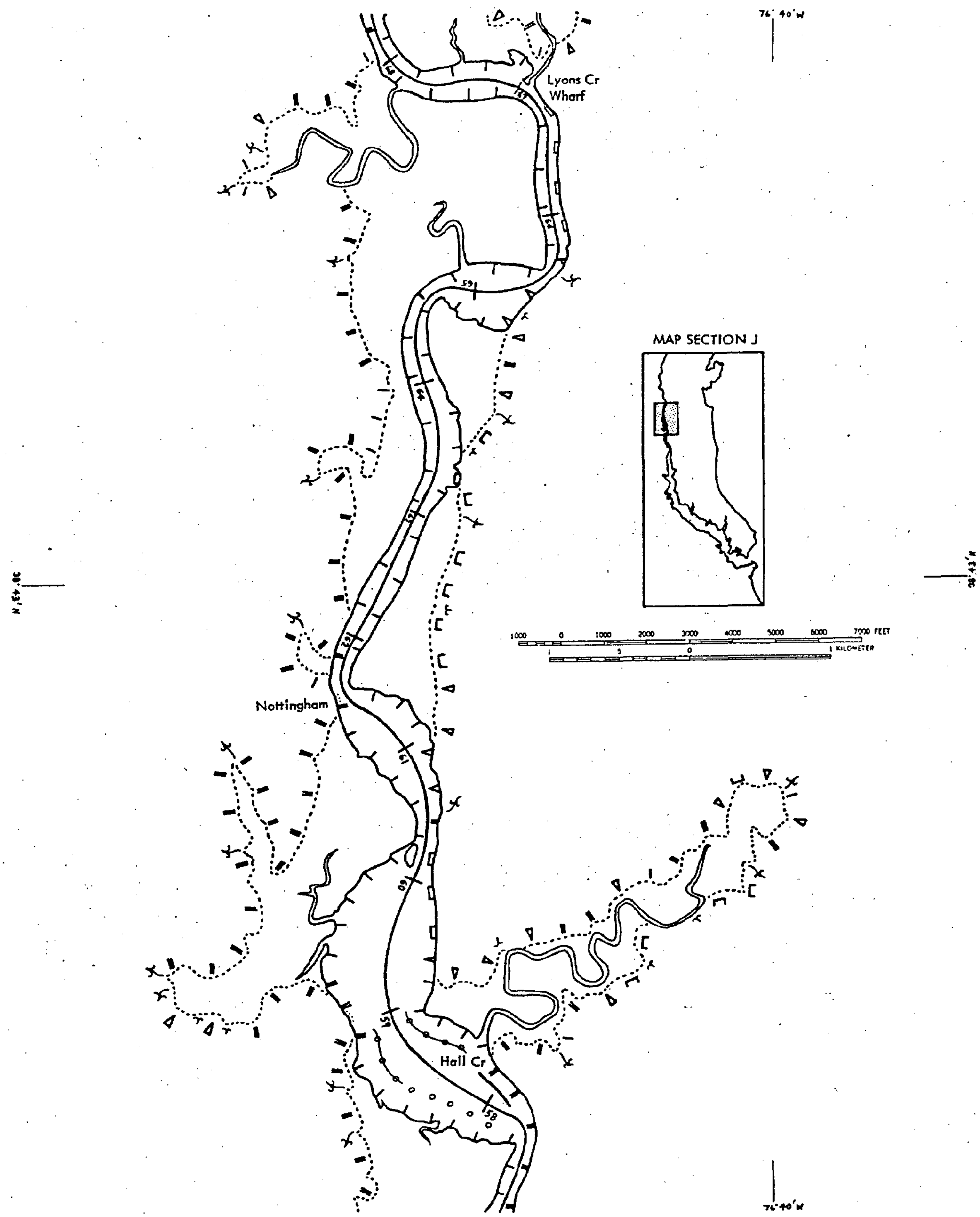

MAP SECTION E
76°38' W
26
25
24
23
Jack Bay
Sandgates
38°25' N
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER


MAP SECTION F
76°37'W
38°27'N
Kitt Pt
Battle
Creek
Jack
Bay
27
26
25
FEET
KILOMETER

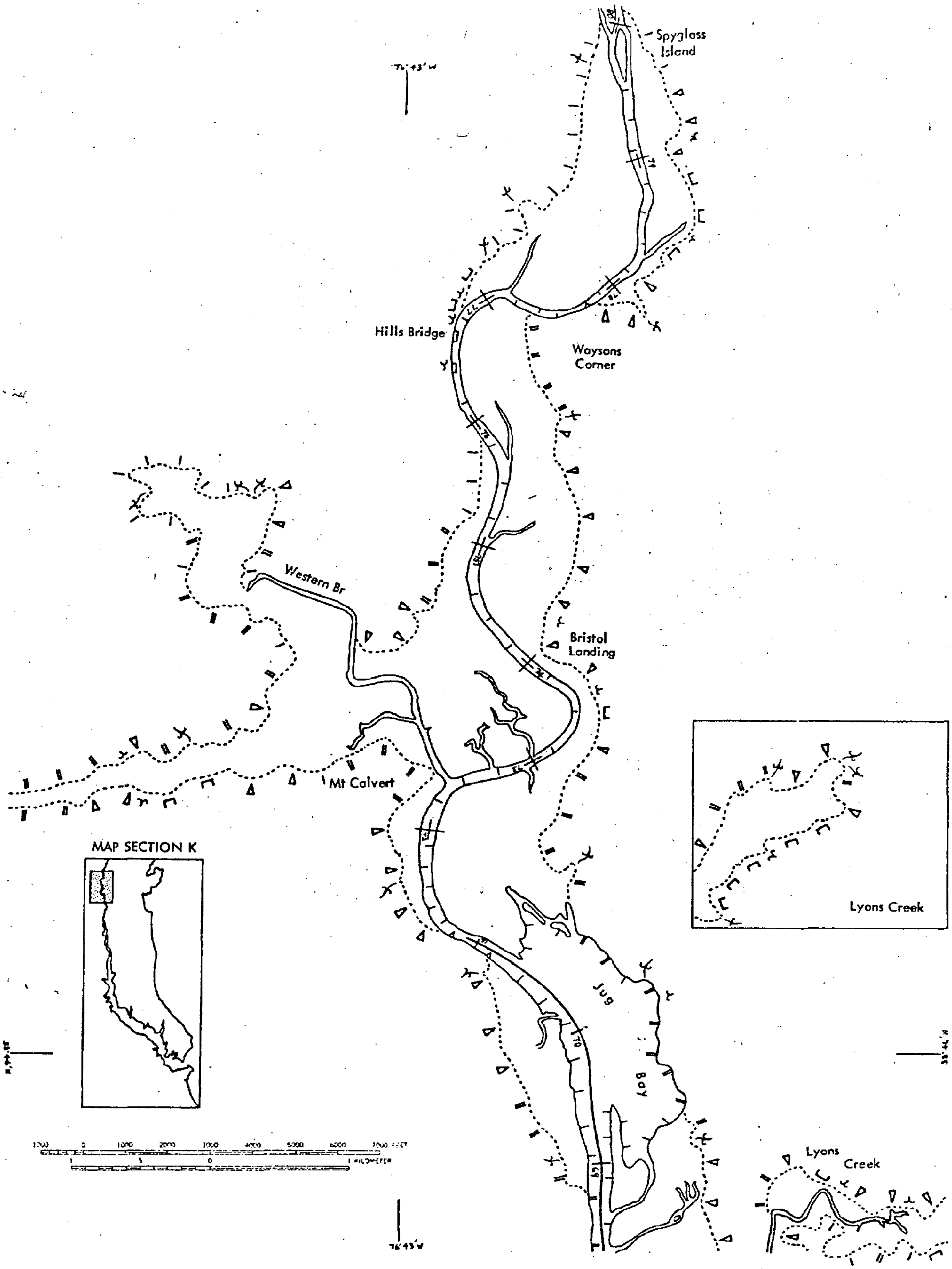

76°42'W
Benedict
Hallowing Point
Indian Creek
Buzzard I C.
Trent Hall Creek
Sheridan Pt
38°29'N
MAP SECTION G
FEET
KILOMETER
36
35
34
33
32
31
30
29
28


76°42'W
Hunting Creek
Hunting Creek
Swanson Creek
MAP SECTION H
38°32'N
38°32'N
76°42'W
45
44
43
42
41
40
39
38
37


76°43'W
White
Landing
Lower Marlboro
38°39'N
38°39'N
Magruder
Landing
MAP SECTION 1
Holland
Cliff
76°43'W



76° 40'W
Lyons Cr Wharf
MAP SECTION J
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
Nottingham
Hall Cr



Spyglass Island
Hills Bridge
Waysons Corner
Western Br
Bristol Landing
Mt Calvert
Jug Bay
Lyons Creek
MAP SECTION K
Lyons Creek